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REVIEWS

Glacial Erosion in France, Switzerland, and Norway. By WILLIAM MORRIS DAVIS. Proc. Bos. Soc. Nat. Hist., July 1900; 49 pp., 7 figures, 3 plates.

In this admirable essay Professor Davis gives cogent reasons for modifying his former views relative to the efficiency of glaciers as erosive agents. A gradual change from a former conservative opinion which had been in progress in recent years was greatly accelerated by his studies in the Alps, Norway, and France during the past year. These studies lay along those topographical lines which Professor Davis had cultivated for the past two decades with such eminent success. They çentered on the great discordance which he observed between the main and the tributary valleys when the former have been occupied by ice streams and the latter have not, or at least have not been effectively modified by glaciers. The tributaries in such cases have been styled by Gilbert "hanging valleys" because, instead of joining their primaries on well-adjusted normal gradients, they enter high up on the side walls. The tributary streams cascade down an abrupt declivity in entering the main glaciated valley in a manner quite out of harmony with their normal behavior within the tributary valleys above or in the glacial valleys below. Associated with the topographic break between the tributaries and the glacially worn primaries there are contrasted physiographies that point, as it seems to the author, and to the reviewer as well, unequivocally to the origin of the phenomena. In the tributary valleys, although in Pleistocene times they were involved in the general glaciation of the region, in some measure at least, the characteristic configuration of weathering and of water erosion clearly predominates, while in the main valleys, which have been the chief channels of glacial movement, flat bottoms and precipitous sides, bearing the peculiar aspects of glacially worn troughs, prevail. No observant traveler in Switzerland has failed to note the numerous small streams that cascade down the abrupt walls of the glaciated valleys. The numerous falls of Aar Valley, especially that portion immediately below the Unter-Aar glacier, is a familiar and striking example.

Although these phenomena have long been noticed and some appreciation of their signification has been felt, it remained for a master in modern physiography to see and to set forth their fuller meaning. It is assumed that in the pre-glacial times the tributaries joined the trunk streams in the normal way with well-adjusted gradients, and that the discordance now shown is the result of the superior erosion of the trunk valleys by the glacial tongues that occupied them. The amount of the discordance is, therefore, taken as a rough measure of the superior erosive efficiency of the glaciers. In the Alps this is recorded in hundreds of feet, and in Norway it reaches into the lower thousands, and gives an impressive illustration of the erosive power of glaciers.

There are, however, several qualifications to be applied to this rough measure, and these are rather more complicated, and perhaps more important, than one might apprehend from reading the paper, though they do not seriously affect its method or its conclusions. In the broadening of the main valley by glacial erosion the mouths of the tributaries were cut back and the present points of intersection lie at higher levels than the original axis of the main valley. This is theoretically restored by projecting the gradient lines of the tributaries till they meet in the center of the main valley. For the main purposes of a general view, such as is sought by the paper, it is, doubtless, sufficiently near the truth to project the present lines of the tributary valleys without modification, but in stricter studies it is necessary to recognize the changes which the tributary valleys have undergone while the main valleys were being deepened by glacial erosion.

If unobstructed erosion was in progress in the tributary valleys while the main ones were being excavated by glaciers, the discordance between the two at the close would measure the *difference* in the rates of erosion of glaciers and of ordinary agencies, and a plus correction would be necessary to secure the absolute glacial erosion. During a part of the glacial period the tributary valleys were smothered in a general mantle of ice and suffered glacial modification as well as the main valleys, but not in just the same way. The main valleys lay in the chief direction of ice movement, for they determined it. The tributaries in the main lay more or less athwart the ice movement. They must hence be presumed to have suffered more or less of rasping down of their rims and of filling up of their axes, and they thus assumed lower reliefs and flatter lines. The projection of their lines thus modified would not accurately represent the true preglacial lines. If the general glaciation sustained a large ratio, dynamically speaking, to the local or valley glaciation, this modification might introduce an error of some moment. As a matter of fact, however, judging from what we know of the general glaciation of the Alps, it probably was not very material. It is less easy to say what may be true of Norway, where general glaciation was much more important both actually and relatively.

In the advancing and retreatal stages of the several glaciations another group of influences came into play. The main valleys were filled by glacial tongues which more or less effectually blocked up the mouths of the tributaries, checked erosion in them, and induced filling, as may be seen in many such valleys today in the Alps, in Greenland, and elsewhere. The valley occupied by the Märjelen See may be cited as a familiar and striking example. While the mouths of the tributary valleys were thus blocked up, their rims were being degraded and a change was thus being wrought in their configuration. The effect of this class of action was to give the tributary valleys not only gentler declivities than they had preglacially, but gentler even than they would have acquired in the natural degradation of the basin had it remained open and free from ice throughout. The result may be styled a premature maturity, for it was not strictly normal to valleys at such positions in the general drainage system. It was a maturity of a local nature hastened by the establishment of a transient base-level at the mouths of the tributaries by the obstructing ice.

This special phase of the reshaping of the tributary valleys, being of the erosive type and being aided by the special climatic conditions of the time and by the high declivities of the valley sides, doubtless quite rapidly removed the signs of the previous subduing effects of general glaciation and restored an aspect resembling the preglacial one without being such, and hence made it difficult to distinguish this pseudo-maturity, if it may be so called, from such degree of maturity as had been attained in preglacial times, or, if you please, such an ideal stage of maturity as would have been reached by subærial erosion had not glaciation interfered. A restoration of the preglacial conditions of the main valley based on the lines of this pseudo-maturity of the tributaries would obviously involve error. Its amount depends on the value of these phases of action, and that in turn is dependent on the duration and complexity of the glacial period.

A strict discussion is constantly vexed by the question whether the competency of the glaciers to erode is to be measured by the absolute amount of work done by them during their existence, be it longer or shorter, or by the ratio of the work they do to that which would be done by the usual erosive agencies in the same area and for the same time. Are we trying to determine the absolute or the relative ? The latter is probably the truer basis of estimation in general, but both have their special values.

In the case in hand, such degradation of the tributaries at their mouths as took place during the period of glaciation lowered the base of reference by which the glacial erosion is measured, and a plus correction is required to give its absolute amount as already indicated. The lowering of the gradients and the premature flattening of the tributary basins, if uncorrected, leads to an erroneous projection of lines across the valleys and requires a negative correction in absolute measurement, and a more complicated and serious correction in relative measurement.

These suggestions do not cover the whole case, but they go as far as is perhaps permissible in a review, indeed, not unlikely farther than is warranted in the review of a paper based on fugitive studies that do not claim an exhaustive character. The importance, or otherwise, of the qualifications suggested depends much upon the duration and the fluctuations of the glacial period and the ratio of the general glacial action to the local valley phases.

If there is any reference in the paper to similar discordances between main valleys and tributaries not in any way connected with glacial erosion, it escaped the eye of the reviewer. Such cases of declared form exist and might naturally be expected to find at least passing recognition in a paper founded on discrepancies of this kind, the more so because in this neglected class also the main valleys are discrepantly broad and deep and the tributaries cascade down into them not unlike those described in the paper, though much less strikingly. Probably the neglected case has little application to the Alpine valleys discussed, and perhaps only an unimportant application to those of Norway. The case referred to arises from changes of drainage, whereby large volumes of water are thrown into valleys that had previously carried much less; such cases, for example, as the Upper

Ohio and the Upper Missouri. In these cases the great accessions of water have broadened and deepened the main channels out of all concordance with their tributaries. These at some distance back from the trunk streams run in their old valleys slightly modified, but as they approach the main valley, they rush down through new gorges, not, indeed, as steep and picturesque as those of the Alps or of Norway, but of like type. These have for some time been distinctly recognized, and are in constant use as working criteria in discriminating earlier and later systems of erosion, involving changed conditions. (See "Further Studies of the Drainage Features of the Upper Ohio Basin," Am. Jour., Sec. XLVII, April 1894, pp. 261–262.)

It seems to have been demonstrated that in Norway the glacial summit was some distance east of the present topographic divide and that hence the Norwegian valleys were called upon to carry away an amount of drainage greater than that which normally belonged to them in preglacial times. This took the form of ice at certain stages, and of water issuing from the edge of the ice field at other stages. How far this may have contributed to the observed result it is hard to guess without knowing more of the detailed history of the glacial period in that region, but it illustrates the connection of this mode of origin of discrepancies between trunk streams and tributaries with similar discrepancies of a true glacial origin. It is probable that even in the Alps, partly by topographic modification and partly by superior condensation, glaciation has concentrated an exceptional amount of drainage in the trunk valleys.

It is not probable, however, that any or all of the modifications herein suggested, or any others, seriously affect the representative truthfulness of the rough estimate of the superior erosive power of glaciers founded on discordance between the tributary hanging valleys and the glaciated trunk valleys. The paper is a valuable contribution to the doctrine of glacial erosion, and is likely to be the more influential with those holding opposite views because it comes from one who has heretofore held a conservative position on the subject.

The reviewer does not, on first reading, sympathize fully with the effort of Professor Davis to extend the analogy of river erosion so unreservedly to glacial work as done in the paper. The analogy is truer in gross externals than in refined analysis. A river erodes by virtue of its pressure and momentum, scarcely at all by rigidity. Very largely its work is done by the striking force of particles driven rapidly against the valley walls and bottom, or against each other. This is largely true even of the pebbles rolled on its bottom, as anyone may see by examining the nick-marks that cover their surfaces and that sharply distinguish them from glaciated pebbles, or by critically comparing a waterworked surface with a glacially worn surface.

On the other hand a glacier does its work by virtue of its rigidity and pressure, and scarcely at all by its momentum, for its velocity is very low. A river with the same velocity as a glacier would be almost absolutely inert as an abrading agency. In the judgment of the reviewer no one is entitled in the present state of evidence to assume that the laws of fluids control the action of glaciers except in external similitude, which is due to the fact that gravitation is the dominant factor in both cases. In convenient and popular exposition the similitude has many advantages, but in framing scientific doctrine and nomenclature, and still more in mental procedure, it is attended by danger. It is doubtless as important to avoid the similitude in critical work as it is permissible to use it in easy exposition.

T. C. C.

Bartholomew's Physical Atlas: An Atlas of Meteorology. Vol. III. A series of over four hundred maps. Prepared by J. G. BARTHOLOMEW, F.R.S.E., and A. J. HERBERTSON, PH.D., and edited by Alexander Buchan, F.R.S. Under the patronage of the Royal Geographical Society. Edinburgh, 1899.

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